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TITLE SMALL ROCKET TORNADO PROBE

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SMALL ROCKET TORNADO PROBE

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ABSTRACT

A small, light weight, under a pound, paper rocket tornado probe has been developed and deployed this season in an attempt to measure the pressure, temperature, ionization, and electric field variations along a trajectory penetrating a tornado funnel. The requirements of weight and materials are set by federal regulations and scientifically one would like one-meter resolution at a penetration velocity of close to Mach 1. We have achieved these requirements by telemetering a strain gage transducer for pressure, micro size thermister and electric field, and ionization sensors via a pulse time telemetry to a receiver on board an aircraft that digitizes a signal and presents it to a Z80 microcomputer for recording on mini-floppy disk. Recording rate is 2 ms for 8 channels of information that also includes telemetry RF field strength, magnetic field for orientation on the rocket, zero reference voltage for the sensor op amps as well as the previously mentioned pressure, temperature, electric field and ionization. The absolute pressure is recorded as well as differentially with times 10 gain. Tactically, we have flown over 120 hours in a Cessna 210 this tornado season; April and May 1981, and encountered one tornado May 22, 70 miles west of Oklahoma City. Four rockets were fired at this tornado, missed, and there were many equipment problems. The equipment needs to be hardened and engineered to a significant degree, but we believe we have proved the feasibility of the probe, tactics, and launch platform for future tornado work. The approach to a tornado is simpler than flying along side the thunderstorm because of the general lack of turbulence in the neighborhood of a tornado, but the logistics of thunderstorm chasing from a remote base in New Mexico is a major difficulty and reliability of the equipment another. We have fired over 50 dummy rockets to prove trajectories, stability, and photographic capability. We have fired over 25 electronically equipped rockets to prove sensors, transmission, breakaway connections, etc. We have calibrated the pressure recovery factor in the Air Force Academy blow-down tunnel. We admit the need for more refined engineering and more logistic support.

A tornado rocket probe must fly at close to MACH 1 in order to penetrate a tornado and not have its trajectory severely perturbed by the tornado velocities. Such a rocket, its instrumentation, and telemetry must weigh less than a pound

and be made of paper to meet FAA regulations and the rocket motor must contain less than 60 g of propellant to meet federal regulations of a non-lethal weapon.

Figure 1 shows a cross section of the rock the engine, and fins were designed and made by George Roos of Flight Systems, Burns Flat, Oklahoma, and the radio telemetry system by Mike Exner of Synergetics, Boulder, Colorado. The computer recording system in the plane was designed and built by Ron Lingeman of Otrons Corporation, Boulder, Colorado. The sensors and their associated amplifiers have been constructed with the aid of students at New Mexico Tech and are shown on the succeeding figures. The battery is a 9-volt alkaline transistor battery that can be recharged while on the launcher so the rocket does not need to be taken apart for new battery insertion. Externally on the rocket are the launch lugs, antennae, nose cone, electric field sensor, and battery bypass breakaway connections.

Figure 2 shows a cutaway of the nose cone that includes the entrance air path to both the pressure and temperature transducers as well as the ionization detector. The recovery factor of the nose cone has been measured in the blow-down tunnel of the US Air Force Academy to be 80%. The thermistor is a 0.007-in. diameter bare bead thermistor that is coated with Krylon to reduce sensitivity to liquid water. The pressure gauge is a sealed pill box made of 40-mil plastic with a solid state strain gauge glued to its surface. The ionization measurement is performed by the current detected between two concentric tubes with a air flow corresponding to 1/10 the area of the input air path.

Figure 3 shows the various components of the nose cone in greater detail and Figure 4 shows the electronic circuits used to amplify the various signals before interfacing to the multiplexer and transmitter.

Many aspects of the system need to be improved. Originally, the rockets were planned for booster launch from the plane in order that the firing delay of the main engine, 1.6 s, did not perturb aim at final approach to a tornado. These have since been dispensed with because of reliability. A record is shown in Fig. 5 of an unboosted rocket fired at 14,500 feet into a thunderstorm in northern New Mexico, May 31, 1981. The data have been transferred from the Z80 computer to the atmospheric science Prime computer at New Mexico Tech for preliminary data processing and graphing. The time coordinate is not yet fully resolved but is given instead in terms of record number. Each record consists of 16 frames of 8 channels of data, each one of roughly 2 ms so that a record number unit is 32 ms. The actual time is recorded by the computer and must be scaled by the integral total signal strength. This analysis has yet to be completed. The top two traces of ionization and electric field are meaningless because of breakaway voltage mismatch. Graph Fig. 5c shows the pressure as a negative signal with its calibration. The peak signal level corresponds to a change in pressure at the transducer of .55 atmospheres or Mach 1.06 flight at 14,500 feet and a

recovery factor in the nose cone of 80%. Figure 6a is the corresponding temperature trace showing $\Delta T = 70^\circ \text{C}$ and again with the same recovery factor, Mach 1.1 is calculated. This is satisfactory agreement with the pressure record. The magnetic field trace is badly distorted, again because of breakaway connection voltage mismatch and the differential pressure trace in Fig. 6c shows an amplified differentiation of the pressure curve. The noise spikes in all traces are dropouts on the telemetry which, inadvertently, is due to the polarization of the transmitting antenna and the receiving antenna. Figure 7a shows this oscillation of the received RF signal strength as the rocket rotates in flight. In Fig. 7b is shown the reference voltage that goes to all the amplifiers as the middle-of-range zero level. The fact that this recording shows remarkable constancy is indicative of the stability of most of the instrumentation. Earlier this same rocket with instrumentation transmitted from the ground and was received on the aircraft several miles distance. The trace in Fig. 8c shows the pickup on the magnetic detector from nearby ac power line of $\pm .3$ gauss.

Three photographic systems are used to record the flight of the rockets relative to a target. These are a Super 8 movie camera, two 16-mm gun cameras (one for each wing) and an auto-wind two frames/s, 32-mm camera. The pilot load with this much equipment has proved excessive.

Two photographs are included - Fig. 9 is the outline of the tornado May 28, 1981, from a color 16-mm frame and Fig. 9 is from a 33-mm slide of an unstable rocket flight due to a fin being stripped at launch. The problem, the diagnosis, and solution are all typical of the project. Current flights are all straight and stable.

Over half the project is concerned with the search tactics directed by the National Severe Storms Lab "now" forecasting center under the direction of Don Burgess. The decision to fly and where is determined in the morning on a daily basis and the actual approach to thunderstorms is selected on the basis of a Ryan's storm scope. Various communication channels with NSSL have been attempted, but a successful search in the future will have to depend upon the ground search-team radio. The rocket tornado probe could be fired equally well from a land vehicle or a helicopter.

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I am deeply indebted to a very large number of people who have helped with this project from its inception, among whom are Joe Golden, NOAA; Eric Dillon, Richard Carlson, Kevin Meier, and Paul Clement, all of New Mexico Tech. Don Burgess and staff at NSSL have been a major and consistent support as well many other members of the laboratory.

Fig. 1. Outline of the rocket probe showing the principal components of nose cone with a pressure transducer and thermister as well the ionization gauge. This is followed by the sensor electronics board which develops the appropriate voltages as well as amplifiers and includes the magnetic field sensor for rocket orientation. Following that is the battery, which is a 9-volt transistor battery of the alkaline type so that it can be recharged without dismantling the rocket. Following that is the multiplexer and transmitter that drives the antennae and then the rocket engine which boosts the rocket to Mach 1.

Fig. 2. Blowup of the nose cone which shows the entrance air path which is large enough such that the flow through the ionization gauge can give an appropriate measurement of ionization as well as a large enough flow for both the thermister and a pressure measurement with the short time scale required. The weep holes in the ionization tube at the aft of the nose cone are such as that flow through these holes is corresponds to 1/10 of the cross section of the input air path. This 10% flow through loss as well as the nose cone shape is what determines the 80% pressure recovery factor determined in the blow-down tunnel of the US Air Force Academy.

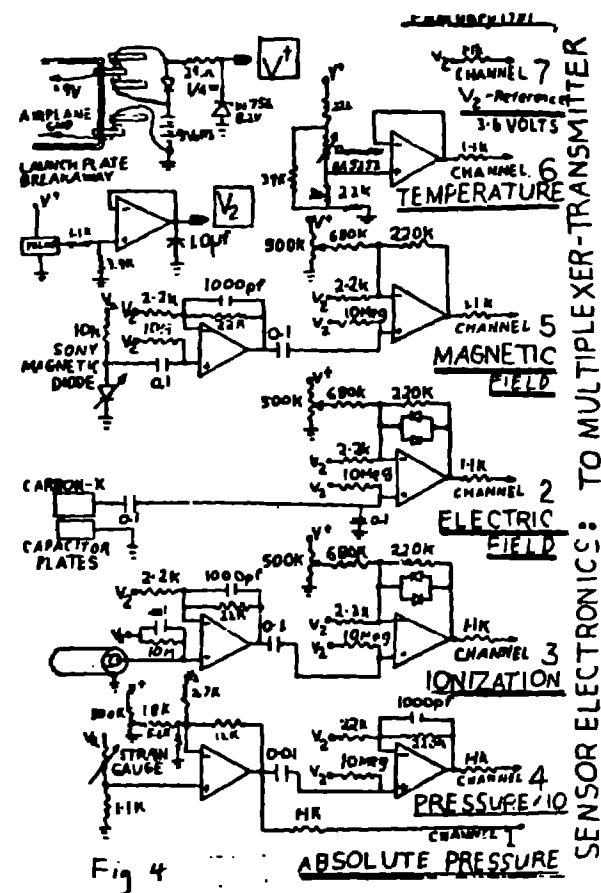
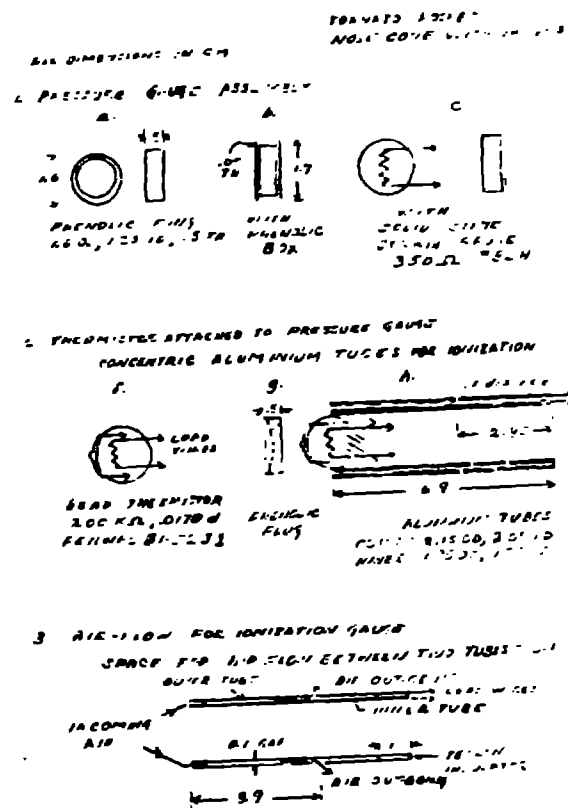
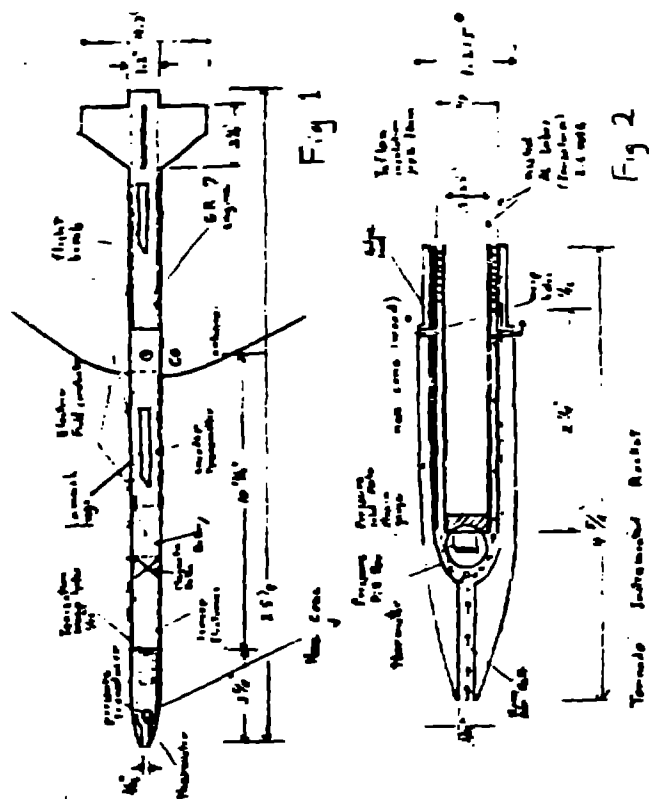
Fig. 3. A blowup of the nose cone and the construction of the pill box with a solid state strain gauge. This is the primary pressure measurement. Solid state strain gauges are quite sensitive to temperature and so there is a small thermal insulation over the solid state strain gauge to reduce the temperature sensitivity during the finite time of the flight.

- Fig. 4. Outline of the electronics. One notes that the electric field and ionization final amplifiers are differential log amplifiers so that the signals are greatly compressed by 100:1 at maximum range. The reference voltage, V_2 is derived from an accurate, 1/10%, voltage regulator and is used as the reference signal for all other sensor signals. It is separately transmitted and recorded in flight so that one has an accurate measurement of the stability of the circuits.
- Fig. 5. Graph of the data of one flight, rocket No. 29 on May 31, 1981, fired at a thunderstorm in northern New Mexico from an altitude of 14,500 ft. A pressure signal relative to the scale of 1 atmosphere corresponds to a Mach 1.06 flight. The electric field and ionization records are essentially meaningless because of a problem of voltage offset at rocket breakaway. In this case no booster was used so that the rocket develops thrust only 1.6 s after ignition so that the breakaway signal of 1.6 s shows up at a time of roughly record number 48.
- Fig. 6. The temperature, magnetic field, and differential pressure measurement are shown. The temperature measurement of 70° C differential corresponds to Mach 1.1 flight and the magnetic field sensor with its high gain is nonoperable again because of breakaway voltage offset. A similar factor shows up on the differential pressure measurement with times 10 gain but the curve in the region of record numbers 80-150 is consistent with a differential of the pressure curve of Fig. 5c.
- Fig. 7a. The RF signal strength received on the airplane. The oscillations are indicative of the rotation of the rocket and the problem of antenna polarization. This leads to the dropouts of the signal, and noise on the record.

Fig. 8. Three measurements of the same rocket when the rocket was on the ground prior to the thunderstorm launch ~~held~~, and powered by its own battery, but with a plane approaching from 2½ miles distance. One can see on the magnetic field record 60-cycle oscillations from a nearby power line. *the*

Fig. 9. A blowup of one frame from a 16-mm gun camera when a tornado was approached and fired at on March 28, 1981.

Fig. 10. Shows a flight of the rocket that was typical of the development phase where stability and fin misalignment were a problem. Most rockets show a trajectory which is perfectly straight.



SENSOR ELECTRONICS: TO MUX/TIPLEXER-TRANSMITTER

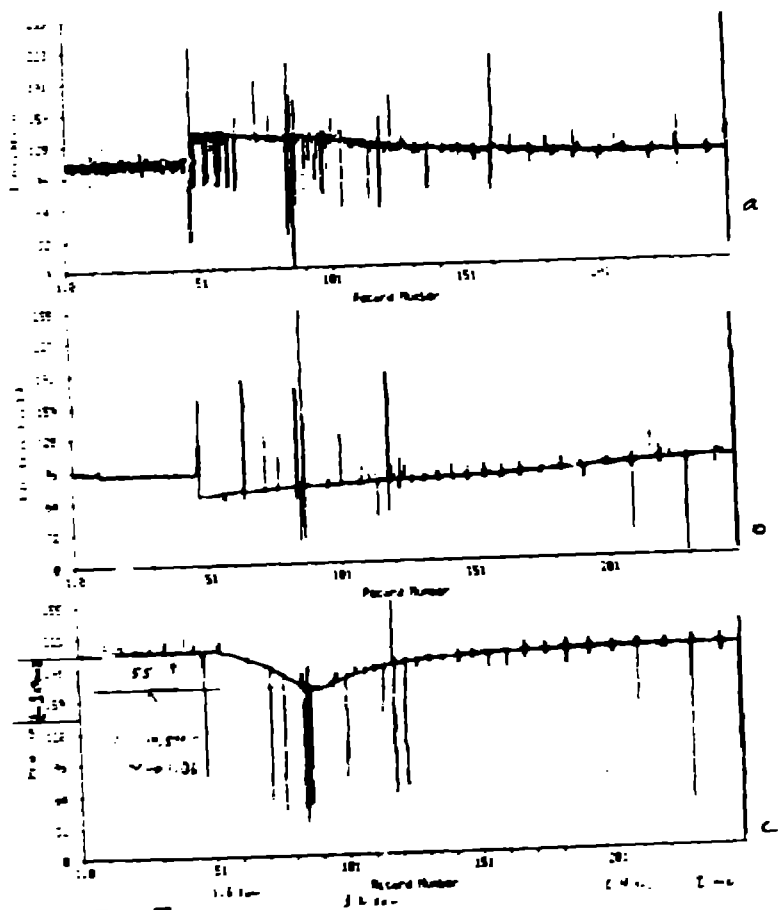


Fig 5

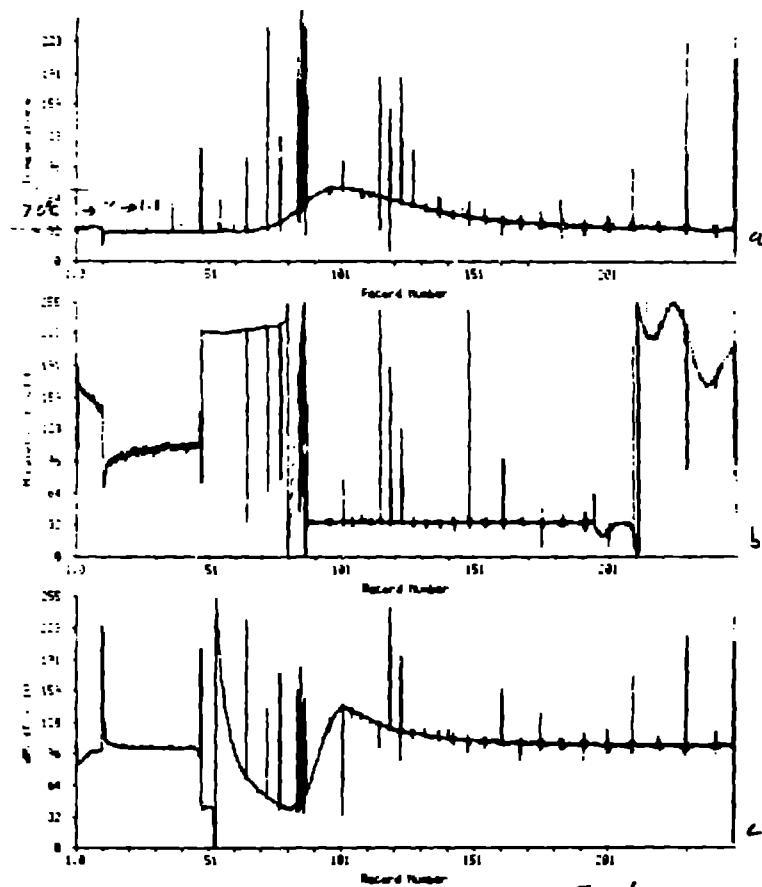


Fig 6

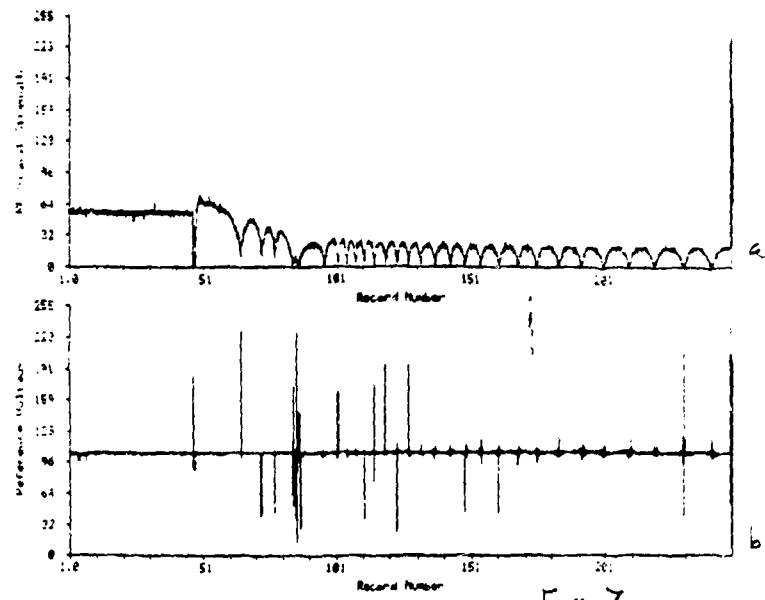


Fig 7

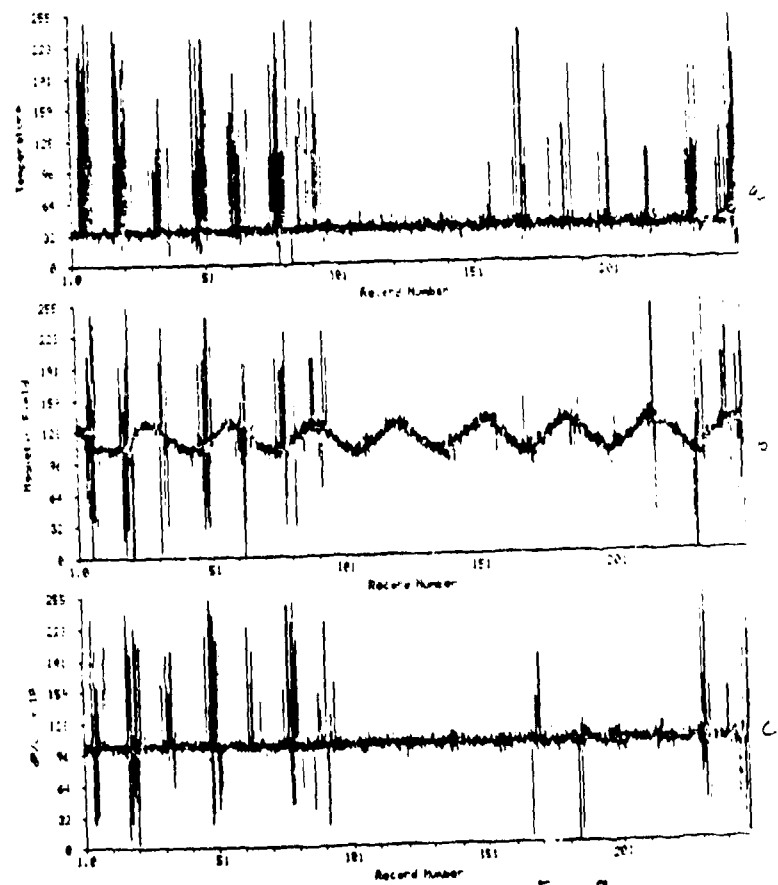


Fig 8

